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Sample Size Versus Sample Number: Sampling Optimization for Trawl Caught Rockfish

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SAMPLE SIZE VERSUS SAMPLE NUMBER: SAMPLING OPTIMIZATION FOR TRAWL CAUGHT ROCKFISH

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ABSTRACT

Stanley, R. D. 1990. Sample size versus sample number: sampling optimization for trawl caught rockfish. Can. MS Rep. Fish. Aquat. Sci. 2080: 19 p.

Estimates of among sample and within sample variance in proportion-at-age for Pacific ocean perch (Sebastes alutus) were used to examine optimum sampling strategies. The results agree with those in the literature to indicate that, for two-stage sampling, a sample size of more than 100 probably represents over-sampling. If reducing sample size will lead to any increase in the number of samples collected, then optimal sample size may be closer to 50. Furthermore, if the resources available for ageing the specimens are limited such that only a fixed number of specimens can be aged from the pool of samples, then specimens should be drawn from as many samples as possible, rather than ageing all specimens from some samples.

RÉSUMÉ

Stanley, R. D. 1990. Sample size versus sample number: sampling optimization for trawl caught rockfish. Can. MS Rep. Fish. Aquat. Sci. 2080: 19 p.

Des estimations de la variance des proportions des classes d'âge dans et entre des échantillons de sébaste à longues máchoires (Sebastes alutus) ont été effectuées de façon à établir des stratégies optimales d'échantillonnage. Les résultats coïncident avec ceux d'autres études publiées et montrent que, dans le cas d'un échantillonnage à deux degrés, un échantillon dont la taille est supérieure à 100 est probablement trop gros. Si le fait de réduire la taille des échantillons permet d'en accroître le nombre, la taille optimale des échantillons seraient alors plus près de 50. De plus, si la détermination de l'âge ne peut être effectuée que pour un nombre limité et fixe de poissons pour l'ensemble des échantillons, il vaut mieux choisir des individus dans le plus grand nombre possible d'échantillons plutôt que de déterminer l'âge de tous les individus de certains échantillons.

INTRODUCTION

Stock assessments for the trawl-caught rockfish fisheries off Canada's west coast have been hampered by a lack of catch-at-age information (Stanley 1988). This shortage is caused partly by the large number of rockfish stocks (Leaman 1989, Stanley 1989) which acts to dilute the waterfront sampling effort. Sampling cruises have been used to supplement the data collection but are costly to conduct on a regular basis. Observer trips on commercial vessels are not cost efficient since the 7-10 day commitment often provides sampling opportunities for only one or two stocks.

Even when sufficient samples are obtained for a given stock, the resources needed to age the specimens are limiting. After allocating the number of aged specimens among the stocks, yearly catch-at-age composition for each significant rockfish stock must be characterized from only 250 specimens.

These limitations place a premium on optimizing the sampling design. In particular, they emphasize the need to examine the tradeoff between number of samples and sample size.

The need to examine sampling strategy was further supported by a review of the literature. Similar studies (Kimura 1984, Sen 1984, Chester and Waters 1985, Hightower 1986) reported that the sampling was optimized by sample sizes of less than 100 specimens, much lower than what was traditionally collected for the B.C. rockfish fishery.

I examined this tradeoff between sample size and number by using collections of aged samples of Pacific ocean perch (Sebastes alutus). Within and among sample variance in proportion-at-age was estimated following the procedures of Cochran (1977) and Chester and Waters (1985). I used the "D-statistic" of Kimura (1984) to represent the collective multinominal variance of the estimates of proportion-at-age. These estimates were then used to examine the effects of increasing sample size or number on precision.

METHODS

I selected from the historical collections all cases where there were 4 or more samples of at least 50 specimens each, representing one stock in one year. The sets of samples were taken from waterfront sampling (landings) and from research cruises (tows) (Table 1). The two sources were not mixed. All specimens were aged using the break-and-burn method (Chilton and Beamish 1982). Twelve cases fit the criteria.

Sample sizes within a case were made equal to the minimum sample size in each case by removing observations at random until all samples were the

same size in a case. Only one version of each altered sample was used. Age observations were grouped into 14 age groups, (≤ 7, 8, 9, ... 19, ≥ 20).

Following Cochran (1977), the age (or size) composition of the catch can be expressed as

$$\bar{p}_j = \frac{\sum_{i=1}^{n} p_{ij}}{n} \qquad (1)$$

where p_{ij} is the proportion of fish in the jth age in the ith landing (or tow); and n is the number of samples (landings or tows).

The sample variance for each proportion can be expressed as

$$v(p_j) = \frac{(1-f_1)s_1^2}{n} + \frac{f_1(1-f_2)s_2^2}{nm} \qquad (2)$$

where f_1 equals the fraction of primary units sampled (n trips sampled / N trips produced by the fishery) and f_2 equals the fraction of elements within the unit (m fish sampled / M number of fish unloaded). The variance of each proportion among sampled sets is expressed as

$$s_1^2 = \frac{\sum_{i=1}^{n} (p_{ij} - \bar{p}_j)^2}{(n-1)} \qquad (3)$$

and, the variance within samples s_2^2 is the expected variance for a binomial proportion

$$s_2^2 = \frac{m}{n(m-1)} \sum_{i=1}^{n} p_{ij} (1 - p_{ij}). \qquad (4)$$

For most of the rockfish fisheries, the sampling fractions can be expected to be negligible, so equation 2 becomes

$$v(p_j) = \frac{s_1^2}{n} = \frac{\sum_{i=1}^{n} (p_{ij} - \bar{p}_j)^2}{n(n-1)} \qquad (5)$$

From Chester and Waters (1985), the variance of each mean age proportion is theoretically the sum of the among sample and within sample variance components, s_a^2, and s_w^2, such that

$$v(\bar{p}_j) = \frac{s_1^2}{n} = \frac{s_a^2}{n} + \frac{s_w^2}{nm} \qquad (6)$$

They state that s_2^2 is an unbiased estimate of s_w^2 and can be estimated from (4). Since s_1^2 is available from (3), we can estimate s_a^2 by subtraction. These estimates of the components of variance can be used to examine how the precision of the estimated proportions varies with sample size and number.

The above statistics were calculated for each age class in each data set.

CALCULATION OF THE "D-STATISTIC"

As discussed by Kimura (1984), some criterion is needed to characterize how well the estimated age distribution can be expected to approximate the true distribution. In this study I have used Kimura's "D-statistic" where

$$D = \sqrt{\sum_{j=1}^{q} v(\bar{p}_j)}. \qquad (7)$$

Expressed in terms of among and within variance,

$$D(m,n) = \sqrt{(a/m+b)/n} \qquad (8)$$

where a and b are the sum of the j estimates of within and among sample variance

$$a = \sum_{j=1}^{q} S_w^2 \qquad (9)$$

$$b = \sum_{j=1}^{q} S_a^2 \qquad (10)$$

The "D-statistic" provides a simple means for characterizing the overall variance when simultaneously estimating proportions from a multinominal distribution. This procedure produces an "average" measure of precision but no longer reflects the precision in estimating one particular age group. For sampling optimization, the intent herein is to generate an overall, relative measure of precision.

It should be noted that in a recent study of optimizing two-phase sampling, Smith (1989) uses the square of D and introduces a weighting factor, k_j such that

$$L = \sum k_j * v(\bar{p}_j) \qquad (12)$$

This allows the investigator to differentially weight the importance of the different proportions. Smith proposes three possible survey objectives: (1) for general analysis, $k_j=1$; (2) for catch curve analysis, $k_j=j$; and (3) for cohort analyses, $k_j=e^j$. I have implicitly used the first option by not using the weighting term.

RESULTS

The ratio a/b reflects the relative contribution of within to among sample variance (Table 2). Greater among sample variance (low a/b ratio), places a higher premium on obtaining more samples. Eight of the cases yielded ratios of 20-70. Four ratios were much lower indicating very high among sample variance. The average estimates of a and b were 0.7169 and 0.0650 which yields a representative ratio of 11.0. Using the average values, equation (8) becomes

$$D(m,n) = \sqrt{(0.7169/m + 0.0650)/n} \qquad (11)$$

Each curve in figures 1 and 2 identifies all the combinations of n and m which yield equal values for D from equation (11). In sampling terms, they represent all the combinations of sample number and sample size which provide equal precision in estimating proportion-at-age.

The estimates of D derived from equation (11) were multiplied by 100 to produce an integer value for ease of comparability in the graphs. For example in Figure 1, an increase of sampling effort which results in a D of 16 instead of 19 (the two lowest curves) indicates that the overall precision increased by 16% (16/19=0.84).

DISCUSSION

The structure of equation (6) is a key to the issue of sample size and sample number. The objective of sampling is to minimize the variance of the estimator, var(p_j). If you increase n, the number of samples, you reduce both terms of equation (6) but if you increase m, the number of fish per sample, just the right-hand term declines. Secondly, even with only a handful of samples, once the sample size exceeds 50, the denominator of the second term becomes very large and this term tends to drop out. Precision is largely determined therefore by sample number provided s_a^2 is not two or three orders of magnitude lower than s_w^2, which translates to a virtual absence of among sample variation. This study and the others referred to above, indicate that this is not the general case. In addition, by increasing sample number it may be possible to sample a significant proportion of the landings. This will increase the value of f_1 (equation 1) and decrease the variance proportionally. It is unlikely that the individual sample size can be increased to represent a significant proportion of the landing (f_2).

While using D (or L) identifies relative precision for examining the tradeoff of sample size versus number, estimation of the absolute precision and confidence limits in the multinominal case is more complicated. Readers are referred to Tortora (1978), Adcock (1987), and Waters and Chester (1987). Sample sizes to minimize or maximize other criteria could be quite different as could the tradeoff between sample size and number of samples.

IMPLICATIONS TO ROCKFISH SAMPLING

Within the context of two-stage sampling, when data from multiple samples are pooled to represent a parent population, it is obvious from Figures 1 and 2 that increasing the sample size beyond 100 specimens provides a marginal improvement in precision. Furthermore, sample sizes of 25-50 specimens, will be optimal if such small samples lead to an increase in the number of samples obtained. For example from Figure 1, 3 samples of 20 specimens produce equally precise estimates as 2 samples of 100.

Figures 3 and 4 indicate the relationship for a more modest estimate of among sample variance. I used an a/b ratio of 50, similar to some of the cases of the present study, and to those reported by Kimura (1984) for Pacific

ocean perch, Pacific hake (Merluccius productus) and petrale sole (Eopsetta jordani). The basic indications are the same although it changes the tradeoff slightly. Three samples of 50 equal two samples of 100.

For a fixed total number of specimens, Kimura (1984) shows that, theoretically, it is generally more efficient to increase sample number rather than sample size. This conclusion is altered when there are significant fixed costs of obtaining a sample regardless of sample size, such as in port sampling, but it applies directly to the allocation of ageing resources. If only a fixed number of specimens can be aged, the best strategy is to age specimens from as many different samples as possible.

Research cruises should be organized to maximize the number of samples. Provided sample size is not below 25-50 fish, sample size should not interfere with the opportunity to obtain more samples.

There are reasons why large (300) sample sizes may be appropriate but these generally apply to situations where one sample provides all the desired information. This would include, for example, a comparison of fin-ray ages to otolith ages. The conclusions presented in this document pertain when multiple samples are pooled to represent one parent population.

Very small sample sizes ($n<20$) may increase the problems of collecting a random group of specimens although it should not present a problem with a conveyor system of unloading. Samplers may have to design a collection procedure that avoids "hand-picking" a few specimens and ensures that specimens of varying sizes have equal probability of selection.

The optimal sampling strategy will also vary slightly with the number of age/length groups, and the weighting process which determines which proportions are of most interest. Waters and Chester (1987) present a graphical method for optimizing sampling given multiple criteria.

CONCLUSIONS

Based on this study and others, it appears that there is generally little benefit in obtaining sample sizes in excess of 100 in the context of two-stage sampling. Furthermore, if smaller sample sizes will lead to more samples then optimal sample size may be closer to 25-50 specimens in the B.C. trawl rockfish fisheries.

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Table 1. List of samples used to estimate sample variance (Res. = research cruise; Comm. = commercial landing).

Case	Stock	Res./Comm.	Date	Sample size Initial	Adjusted
1	Anthony Is.	Comm.	1979 01/31	100	97
			02/21	97	97
			04/17	100	97
			04/27	100	97
			05/03	99	97
			06/06	100	97
2	Area 3C	Res.	1979 09/06	201	100
			09/06	201	100
			09/07	200	100
			09/08	200	100
			09/09	100	100
			09/11	100	100
3	Goose Is. Gully	Comm.	1978 05/19	101	100
			06/08	103	100
			09/26	110	100
			10/10	103	100
4	Goose Is. Gully	Comm.	1979 07/05	100	99
			07/24	99	99
			09/20	100	99
			10/19	100	99
5	Goose Is. Gully	Comm.	1980 05/28	100	100
			06/25	100	100
			06/09	100	100
			06/19	100	100
			07/02	100	100
			07/21	100	100
			08/06	100	100
			09/22	100	100
6	Goose Is. Gully	Comm.	1984 Tow #1	194	99
			2	200	99
			3	100	99
			4	100	99
			5	100	99
			6	100	99
			7	100	99
			8	100	99
			9	100	99

Table 1 (cont'd)

Case	Stock	Res./Comm.	Date	Sample size Initial	Adjusted
6	Goose Is. Gully	Comm.	1984 Tow# 11	99	99
			13	100	99
			14	100	99
			17	98	99
			18	100	99
7	Langara Is.	Comm.	1979 04/15	100	98
			04/28	100	98
			04/30	100	98
			07/02	98	98
8	Langara Is.	Comm.	1984 05/08	200	200
			11/05	200	200
			06/26	200	200
			03/01	200	200
9	Langara Is.	Comm.	1989 13/02	59	59
			23/02	60	59
			13/02	60	59
			22/03	60	59
10	Mitchell's Gully	Comm.	1979 06/19	100	100
			06/28	100	100
			07/03	100	100
			07/05	100	100
			09/05	100	100
11	Mitchell's Gully	Res.	1984 Tow #25	92	92
			26	94	92
			27	100	92
			30	100	92
			33	96	92
12	Moresby Gully	Comm.	1987 28/04	300	200
			24/04	300	200
			27/04	300	200
			14/07	251	200

Table 2. Within and among sample variance by case (Res. = research cruise; Comm. = commercial landing).

Case	Year	Res./ Comm.	S_a^2 (b)	S_w^2 (a)	a/b
Anthony Is.	1979	Comm.	0.0121	0.3926	32.4
Area 3C	1979	Res.	0.0164	0.8917	34.4
Goose Is. Gully	1978	Comm.	0.0166	0.8971	54.0
Goose Is. Gully	1979	Comm.	0.0436	0.8846	20.3
Goose Is. Gully	1980	Comm.	0.0128	0.8900	69.5
Goose Is. Gully	1984	Comm.	0.0562	0.5432	9.7
Langara Is.	1979	Comm.	0.1806	0.5663	3.1
Langara Is.	1984	Comm.	0.0838	0.7242	8.6
Langara Is.	1989	Comm.	0.0214	0.7937	37.1
Mitchell's Gully	1979	Comm.	0.0128	0.8826	69.0
Mitchell's Gully	1984	Res.	0.3022	0.4266	1.4
Moresby Gully	1987	Comm.	0.0213	0.7106	33.4
			$\bar{S}_a^2$=0.0650	$\bar{S}_w$=0.7169	

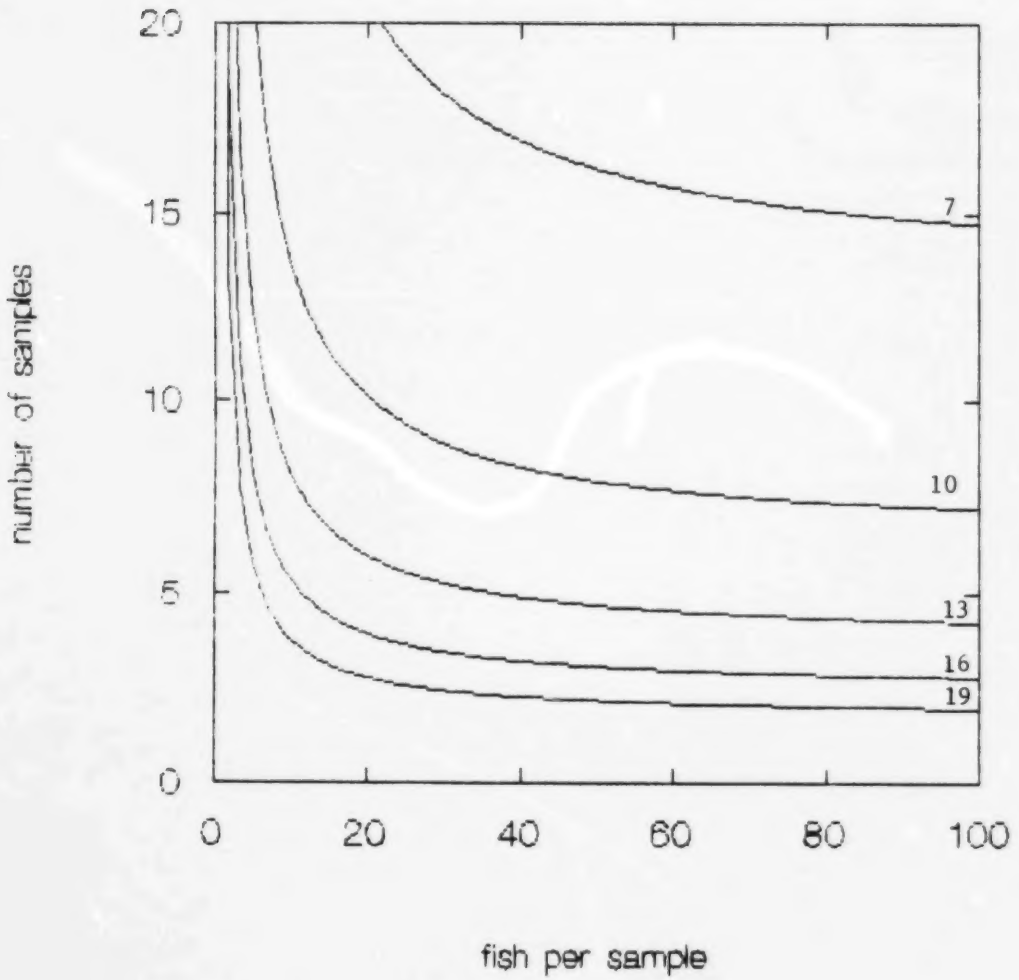

Fig. 1. Contour lines of equal precision, a/b = 11.0.
Values on the curves equal D x 100.

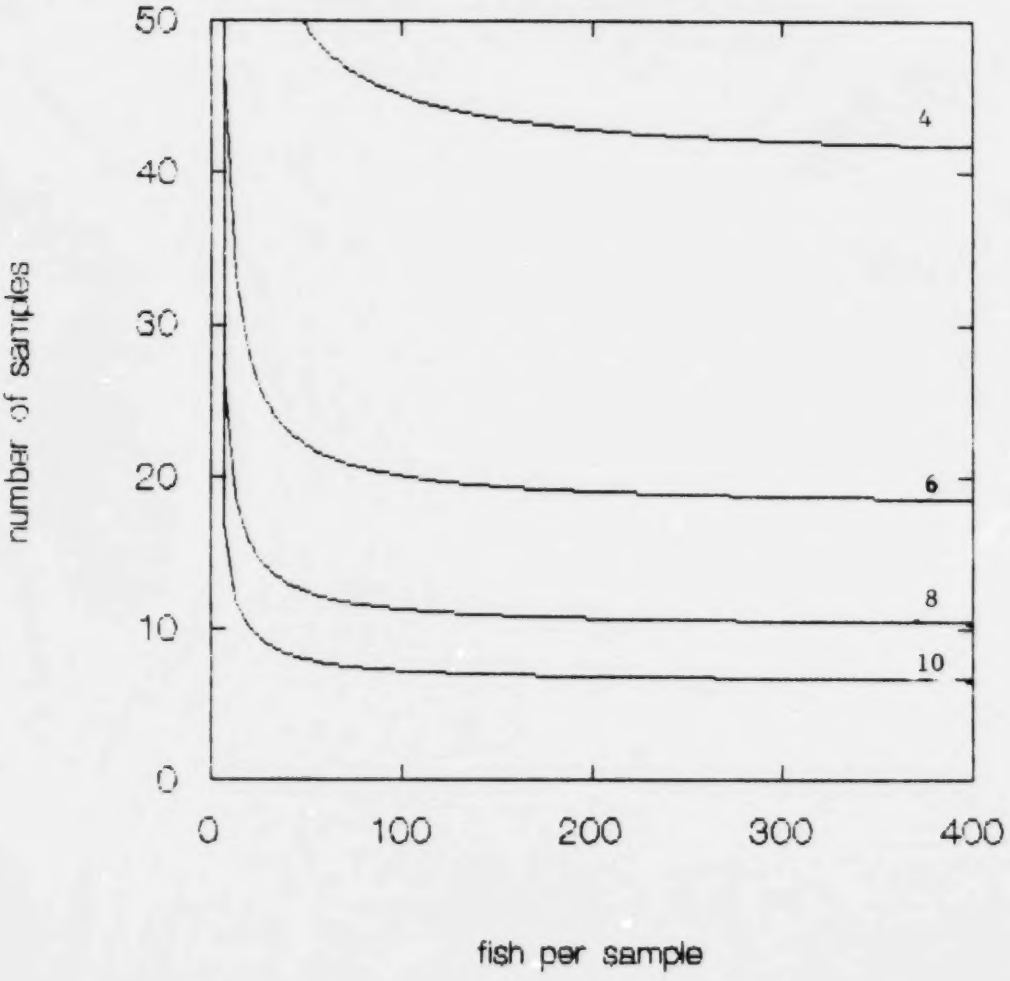

Figure 2. Contour lines of equal precision, a/b = 11.0
Values on the curves equal D x 100.

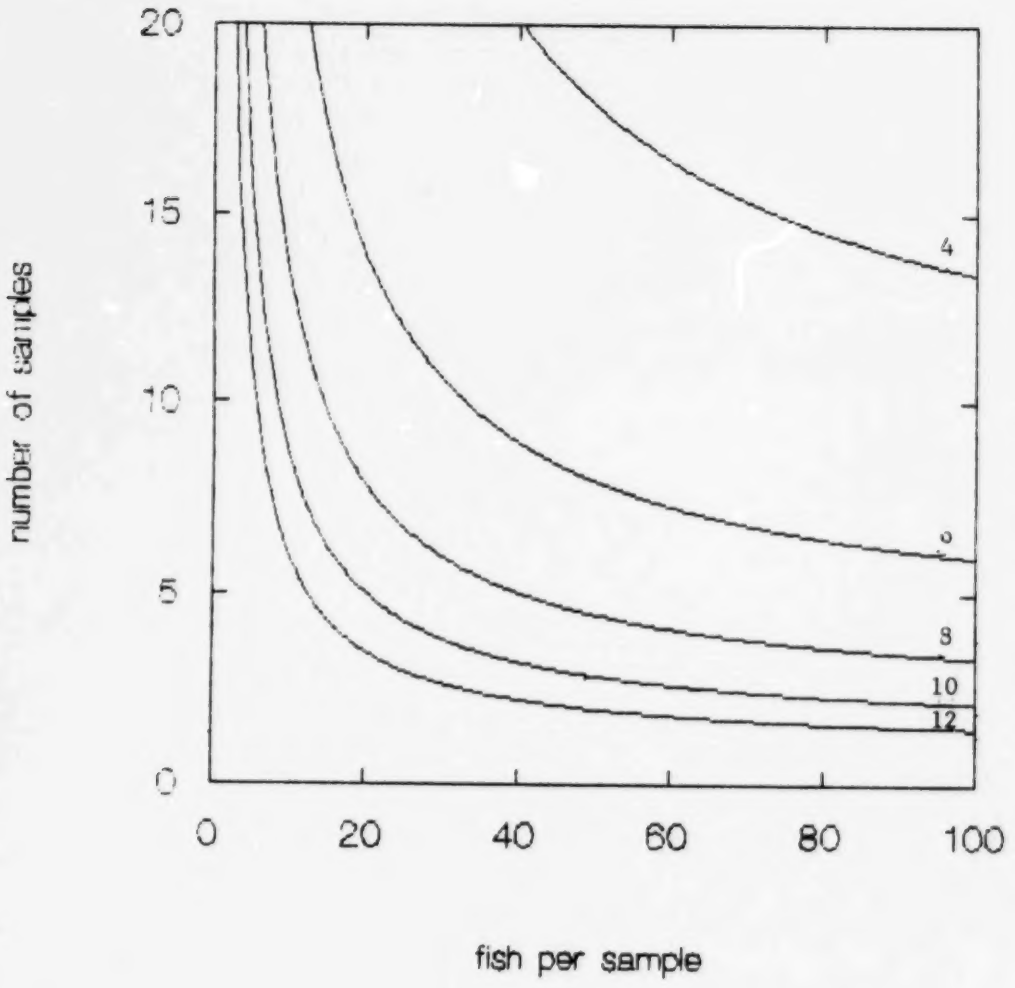

Fig. 3. Contour lines of equal precision, a/b = 50.0
Values on the curves equal D x 100.

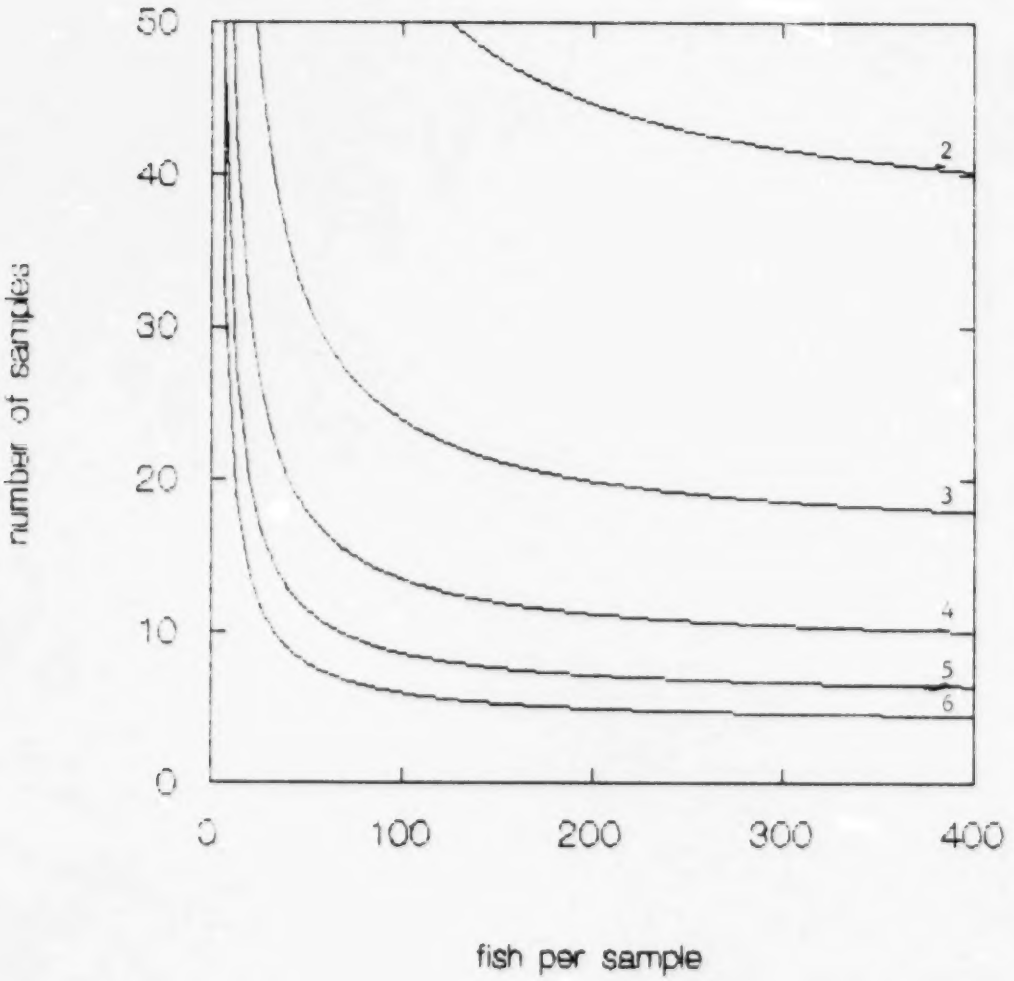

Fig. 4. Contour lines of equal precision, a/b = 50.0. Values on the curves equal D x 100.